ORIGINAL ARTICLE

Robotic Mitral Valve Repair for All Categories of Leaflet Prolapse: Improving Patient Appeal and Advancing Standard of Care

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OBJECTIVE: **To characterize the early outcomes of robotic mitral valve (MV) repair using standard open techniques.**

PATIENTS AND METHODS: **We prospectively studied 100 patients with severe mitral regurgitation due to leaflet prolapse who underwent robot-assisted MV repair using conventional open-repair techniques between January 1, 2008, and December 31, 2009, at Mayo Clinic, Rochester, MN.**

RESULTS: **The mean age of the patients was 53.9 years; 77 patients (77%) were male. Fifty-nine patients (59%) had posterior leaflet prolapse, 38 (38%) had bileaflet disease, and 3 (3%) had isolated anterior leaflet prolapse. Median cross-clamp and bypass times decreased significantly during the course of the study (*P*<.001). Median postoperative ventilation time was 0 hours for the last 25 patients, with most patients extubated in the operating room. No deaths occurred. Reexploration for postoperative bleeding occurred in 1 patient (1%); 3 patients (3%) required percutaneous coronary intervention. Median hospital stay was 3 days. One patient (1%) underwent mitral reoperation for annuloplasty band dehiscence. Residual regurgitation was mild or less in all patients at dismissal and 1 month postoperatively. Significant reverse remodeling occurred by 1 month, including decreased left ventricular end-diastolic diameter (−7.2 mm; *P*<.001) and left ventricular end-diastolic volume (−61.0 mL; *P*<.001).**

CONCLUSION: **Robot-assisted MV repair using proven, conventional open-repair techniques is reproducible and safe and hastens recovery for all categories of leaflet prolapse. One month after surgery, significant regression in left ventricular size and volume is evident.**

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CT = computed tomography; LV = left ventricular; LVEDD = LV end-diastolic diameter; LVEF = LV ejection fraction; MR = mitral regurgitation; MV = mitral valve; TTE = transthoracic echocardiography

The standard of care to correct severe mitral regurgitation (MR) due to degenerative mitral valve (MV) disease is MV repair. In studies comparing MV repair with MV replacement with a prosthetic valve, repair achieved better survival and equivalent, if not better, durability. The availability of a reproducible MV repair technique as a safe and reliable alternative to prosthetic replacement has influenced the indications for surgical intervention in patients with MR due to leaflet prolapse. After successful MV repair, patients who maintain sinus rhythm resume full activities and do not need long-term anticoagulant therapy. Compliance with international guidelines[1] recommending early MV repair has been heterogeneous for 3 main reasons: (1) hesitancy of some otherwise active and asymptomatic individuals to accept the need for an invasive cardiac surgical procedure; (2) reluctance of cardiologists to refer such patients for an operation requiring sternotomy; and (3) concern that MV replacement instead of repair might be performed at the time of surgery.

The growing interest in catheter-based interventions for less invasive approaches has led to the clinical introduction of mechanistically incomplete procedures, such as the percutaneous mitral clip.[2] Rather than expecting that the intricate judgment-based maneuvers of MV repair might be reproduced using a catheter, we considered the use of proven surgical techniques via minimally invasive incisions to present an opportunity to maintain known outcomes while improving patient acceptance and clinical compliance with guidelines recommending early MV repair. The purpose of our study was to determine whether a robot-assisted, minimally invasive MV repair might be safely performed using all conventional open-repair techniques.

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PATIENTS AND METHODS

Between January 1, 2008, and December 31, 2009, a total of 632 patients underwent MV repair at Mayo Clinic in Rochester, MN. Of these, 105 underwent robot-assisted MV repair (da Vinci S HD Surgical System; Intuitive Surgical, Inc, Sunnyvale, CA); 100 provided authorization for their medical records to be used for research purposes. Our data represent a retrospective chart review of these patients. The study was approved by the Mayo Clinic Institutional Review Board. Patients with mitral leaflet prolapse and severe MR were offered surgery in accordance with current American College of Cardiology/American Heart Association guidelines.[1] All patients underwent transthoracic echocardiography (TTE) and electrocardiographically gated volumetric computed tomography (CT) of the chest, abdomen, and pelvis and were seen by a cardiologist and the cardiac surgeon before surgery.

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Robotic MV repair is offered as an option in our valvular heart disease cardiology subspecialty clinics in the same way as any other operation would be offered at Mayo Clinic. The cardiologists refer patients for specific modes of therapy on the basis of certain predetermined criteria. In particular, patients with extensive coronary artery disease requiring revascularization, severe peripheral vascular disease precluding safe groin cannulation, and prior median sternotomy or right thoracotomy were not candidates for robotic MV repair. Patients with evidence of more than 50% diameter stenosis of the coronary lumen on CT underwent cardiac catheterization to confirm the absence of severe coronary disease before robot-assisted MV repair. No other systematic exclusion criteria were used.

Surgical Protocol

Before induction of general anesthesia, 3 single-shot, right-sided paravertebral nerve blocks were performed under ultrasound guidance between T2 and T6. After induction of general anesthesia, a left-sided double-lumen endotracheal tube was placed along with a left radial artery catheter and a multiplane transesophageal echocardiography probe. Two cannulas were placed into the right internal jugular vein. An 8.5F introducer sheath was placed 1 to 2 cm cephalad to the clavicle and later prepared in a sterile fashion into the surgical field. A 16-cm, 8.5F quadruple-lumen catheter for drug and fluid administration and central venous pressure monitoring was placed 3 to 5 cm cephalad to the introducer sheath. Anesthesia was maintained with isoflurane in air and oxygen along with a total of 5 to 8 μg of intravenous fentanyl per kilogram in divided doses. Vecuronium facilitated muscle relaxation.

Patients were prepared and draped in a 30° right-side-up position. A 1.5- to 2-cm incision overlying the right common femoral vessels was made, and heparin was administered, after which rectangular-shaped purse-string sutures were placed in the common femoral artery and vein. Using a Seldinger technique and echocardiographic guidance, a 21F or 25F (Edwards Lifesciences CardioVations, Irvine, CA) multistage venous cannula was inserted and advanced to the junction between the superior vena cava and right atrium. A 16F or 18F cannula was also inserted in a similar manner via the right internal jugular vein into the superior vena cava, with care taken to avoid crossing the 2 cannulas. The internal jugular cannula improved drainage of the right atrium. There were no difficulties associated with placement of the internal jugular cannula. An appropriately sized femoral arterial cannula was then placed via the common femoral artery into the iliac artery or distal abdominal aorta.

Simultaneously, right thoracic access ports were fashioned. The right lung was deflated, and a 1-cm fourth intercostal space camera port was placed 2 cm lateral to the right nipple. The right thorax was insufflated with carbon dioxide to 10 mm Hg, and the correct anatomic approach over the bifurcation of the right pulmonary veins was confirmed videoscopically. After confirmation of the appropriate interspace, a 2- to 3-cm working port was fashioned 2 to 3 cm lateral to the camera port. The right arm port was placed 2 interspaces inferior to the working port, and the left arm port was placed 1 interspace above. Finally, the left atrial retractor port was placed 3 to 4 cm medial to the camera port in the fourth interspace. The pericardium was opened at least 4 cm anterior to the phrenic nerve and suspended on stay sutures, which were then snared and pulled through the right lateral chest wall posterior to the working port, after which they were fixed externally. In each procedure, the surgeon operating the robot was assisted by another fully qualified cardiovascular surgeon to complete the operation safely and expeditiously during cardiopulmonary bypass. Both surgeons were competent in completion of all technical aspects of MV repair and freely exchanged roles during cases. Once the patient was placed on bypass at a flow of 2.4 $L \cdot min^{-1} \cdot ms^{-2}$, a nonabsorbable polypropylene suture (Prolene; Ethicon, Inc, Somerville, NJ) with a felt pledget was placed in the ascending aorta just below the right pulmonary artery. A long tack vent cannula (Medtronic, Minneapolis, MN) was pulled through the chest wall backward to create a straight line of trajectory to the purse-string suture. The needle was then inserted into the cannula, and the robotic instruments were used to guide the cannula into the ascending aorta, which was then snared in place. The transthoracic clamp was inserted through the chest wall along a direct line to the transverse sinus. The heart was arrested with 1 L of cold blood cardioplegia, which was readministered at 20-minute intervals throughout the cross-clamp time. Cardioplegia instillation into the coronary ostia was confirmed using transesophageal echocardiography. Once the heart was arrested, the left atrium was opened with an incision posterior to the interatrial groove to expose the MV. Standard open-repair techniques were used in all cases, and conventional sternotomy mitral repair techniques were not modified for the closed-chest environment. Briefly, full standard triangular resection with 2-layer polypropylene reconstruction was used for posterior leaflet disease, while anterior leaflet prolapse was treated with polytetrafluoroethylene (Gore-Tex; W. L. Gore & Associates, Inc, Flagstaff, AZ) neochord resuspension.[3,4] All repairs were protected, and the annular circumference was corrected using a standard-length posterior annuloplasty band as previously described for all open repairs at our institution.[5] Sutures were tied by the assisting surgeon. Repairs were inspected using saline insufflation, and the left ventricle was filled before closure, deairing, and cross-clamp removal. The integrity of the repair (≤mild residual MR) and adequacy of deairing were confirmed with the patient off cardiopulmonary bypass before temporarily returning the patient to full support for removal of the cardioplegia tack vent and tying of the stitch. Decannulation and reversal of heparin were performed in the usual manner. A 19F soft silicone (Blake; Ethicon) drain was placed in the oblique sinus, and the pericardium was closed with interrupted silk sutures. A 32F chest tube was placed in the posterior diaphragmatic sulcus, and the chest wounds were closed in layers with polyglactin 910 absorbable sutures (Vicryl; Ethicon). Ketorolac, 30 mg, was given intravenously just before skin closure, and patients were extubated in the operating room at the conclusion of surgery before transfer to the intensive care unit. Patients were often transferred to a step-down unit by the evening of surgery.

After hospital discharge, all patients were seen in follow-up 1 month after surgery. All patients underwent repeat TTE, and a subgroup had follow-up electrocardiographically gated volumetric cardiac CT.

Statistical Analyses

Baseline characteristics are reported as mean (± SD) and median for continuous variables and number (percentage) for categorical variables. Change of echocardiographic variables from preoperative status to discharge and 1 month was tested using paired *t* test or Wilcoxon signed rank test when appropriate. The Wilcoxon signed rank test was used to test the change in echocardiogram parameters from preoperative to discharge and at 1-month follow-up. The changes in cardiopulmonary bypass time, cross-clamp time, postoperative ventilation time, and length of hospitalization along chronological quartiles of cases were tested using the Spearman rank correlation test. All statistical tests were 2-sided; $P<.05$ was considered significant.

RESULTS

Baseline characteristics are listed in Table 1. In accordance with current guidelines, 90% of patients who underwent MV repair were minimally symptomatic (New York Heart Association class I or II); 2 patients had moderate to severe preoperative MR grade, and 98 had severe preoperative MR grade.

Fifty-nine patients (59%) had posterior leaflet prolapse, 38 (38%) had bileaflet disease, and 3 (3%) had isolated anterior leaflet disease. Concomitant procedures included closure of an atrial septal defect or patent foramen ovale in 24 (24%) and a left-sided maze procedure in 4 (4%). All patients underwent successful MV repair. Perioperative complications are listed in Table 2. No early deaths occurred. One patient (1%) underwent reexploration for postoperative bleeding. Significant decreases in the durations of cardiopulmonary bypass, aortic cross-clamp, and postoperative ventilation were documented over time when patients were divided into quartiles based on chronological date of operation (Figure; all $P<.001$). There was a trend for postoperative stay to decrease from 4 days to 3 days during the duration of the experience ($P=.05$).

TABLE 1. **Preoperative Baseline Characteristics of Patients Who Underwent Robot-Assisted Mitral Valve Repair**[a]

Variable	Mean ± SD (median) or No. (%) of patients
Characteristic	
Age, y	53.9±11.4 (54)
Male	77 (77)
Body mass index	27.2±3.8 (27.2)
NYHA class I, II	90 (90)
Comorbid condition	
CHF	1 (1)
Diabetes	1 (1)
Hypertension	34 (34)
Preoperative creatinine >2.0 mg/dL[b]	0 (0)
Preoperative atrial fibrillation or flutter	4 (4)
CVA	0 (0)
Transient ischemic attack	1 (1)
PVD	2 (2)
Smoking history	43 (43)
Echocardiographic finding	
LVEF, %	65.8±6.7 (66)
Preoperative MR grade	
Moderate-severe	2 (2)
Severe	98 (98)
LVEDD, mm	58.7±5.4 (58)
LVESD, mm	35.6±4.3 (35)
LAVI	56.1±21.5 (51.5)
ERO[c]	0.5±0.2 (0.5)
RVOL[d]	84.1±32.1 (77)
CT finding	
LVEDV, mL[e]	235.1±58.3 (233)
LVESV, mL[e]	83.4±23.8 (80)

[a] CHF = congestive heart failure; CT = computed tomographic; CVA = cerebrovascular accident; ERO = effective regurgitant orifice area; LAVI = left atrial volume index; LVEDD = left ventricular end-diastolic diameter; LVEDV = left ventricular end-diastolic volume; LVEF = left ventricular ejection fraction; LVESD = left ventricular end-systolic diameter; LVESV = left ventricular end-systolic volume; MR = mitral regurgitation; NYHA = New York Heart Association; PVD = peripheral vascular disease; RVOL = regurgitant volume.

[b] SI conversion factor: To convert creatinine level to μmol/L, multiply by 88.4.

[c] ERO (cm^2) was missing for 16 patients. Results provided were calculated on the basis of data from 84 patients.

[d] RVOL (mL) was missing for 14 patients. Results provided were calculated on the basis of data from 86 patients.

[e] LVEDV and LVESV were missing for 11 patients. Results provided were calculated on the basis of data from 89 patients.

There was only 1 mitral reoperation for annuloplasty band dehiscence, which occurred in a patient with severe Barlow disease and poor tissue quality. This patient also had a stroke and underwent mechanical MV replacement at the time of reoperation. Three patients (3%) required percutaneous coronary intervention, 2 for tethering of the circumflex artery. The third patient had acute thrombus in the

TABLE 2. **Perioperative Complications of Patients Who Underwent Robot-Assisted Mitral Valve Repair[a]**

Variable	No. (%) of patients
30-d Mortality	0 (0)
Late mortality	0 (0)
Stroke	1 (1)
Ventilation (>48 h)	3 (3)
Bleeding requiring reoperation	1 (1)
Any blood product transfusion	15 (15)
PRBCs	13 (13)
FFP	8 (8)
Platelets	6 (6)
Deep infection	1 (1)
Atrial fibrillation	20 (20)
Right diaphragm dysfunction	1 (1)
Median length of stay (surgery to discharge), d	3
MR at 1 mo	
None	15 (15)
Trivial	67 (67)
Mild	18 (18)
Readmission within 30 d[b]	3 (3)

[a] FFP = fresh frozen plasma; MR = mitral regurgitation; PRBC = packed red blood cell.
[b] Atrial fibrillation, dyspnea, and pain control.

right coronary territory with proximal atherosclerotic plaque burden and required temporary mechanical support before recovery of normal biventricular function. One patient had acute heparin-induced thrombocytopenia and thrombosis and underwent bilateral lower extremity compartment fasciotomies. All patients were dismissed with mild or less residual MR. Predismissal TTE confirmed the early decrease in left ventricular end-diastolic diameter (LVEDD) by 6.6 mm ($P<.001$) and a decline in left ventricular ejection fraction (LVEF) by 9.0 percentage points ($P<.001$).

One month postoperatively, MR grade was none or trivial in 82 patients (82%) and mild in 18 (18%). Significant reverse remodeling (compared with preoperative levels) occurred by 1 month, including a decrease in both LVEDD (−7.2 mm; $P<.001$) and left ventricular end-diastolic volume (−61.0 mL; $P<.001$), while LVEF remained, on average, 9.8 percentage points lower than the preoperative level. All patients returned to New York Heart Association class I by 1 month after surgery (Table 3).

DISCUSSION

Early MV repair of leaflet prolapse can prevent the deleterious sequelae of severe untreated MR.[6,7] Approaches less invasive than sternotomy, particularly using robotic assistance, facilitate early resumption of normal activities in otherwise healthy, asymptomatic individuals and

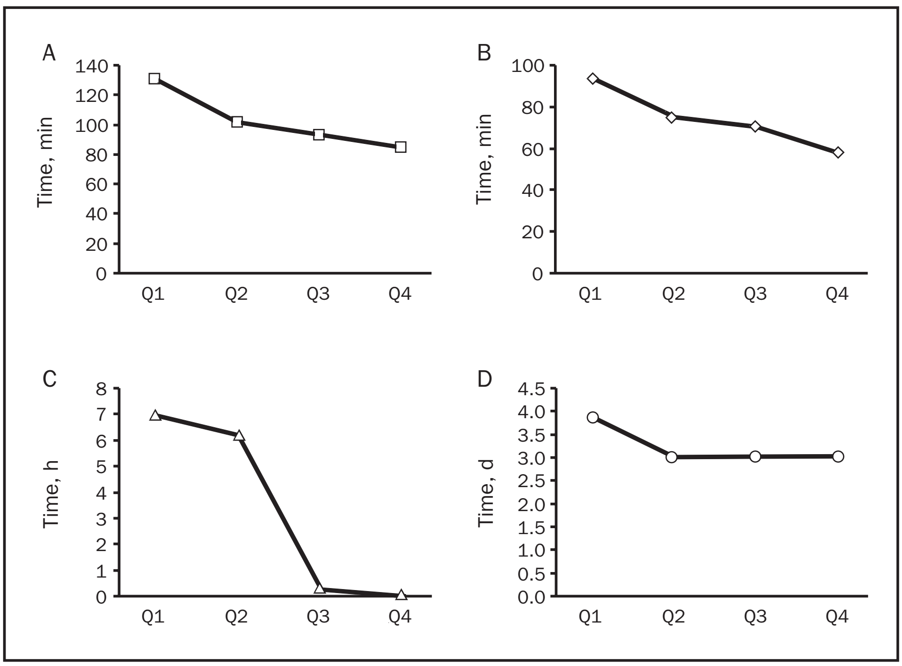

FIGURE. Improvements in outcomes by quartile, based on chronological date of operation. Significant decreases in median cardiopulmonary bypass perfusion time (r=−0.6) (A), median aortic cross-clamp time (r=−0.6) (B), postoperative median ventilation durations (r=−0.7) (C), and median postoperative length of stay (r=−0.4) (D) were documented over time when patients were divided into quartiles based on chronological date of operation (all $P<.001$, Spearman rank correlation test). (One outlier who required a longer duration of ventilation during postoperative mechanical support was not included in the test of postoperative ventilation data between quartiles.)

TABLE 3. **Change in Left Ventricular Size and Function From Preoperative Levels to 1 Month After Robot-Assisted Mitral Valve Repair**[a]

	Mean ± SD (median)		
Variable[b]	At 1-mo follow-up	Change from preoperative level	*P* value
LVEF, %	55.9±7.6 (58)	−9.8±9.4 (−10)[c]	<.001
LVEDD, mm	51.5±4.4 (52)	−7.2±4.5 (−8)	<.001
LVESD, mm	35.6±5.0 (35)	−0.1±4.4 (0)	.91
LVEDV, mL[d]	177.4±34.4 (180)	−61.0±38.7 (−53)	<.001
LVESV, mL[d]	85.2±25.4 (84)	0.9±21.4 (2)	.70

[a] Abbreviations are as defined in Table 1.
[b] LVEF, LVEDD, and LVESD were determined by transthoracic echocardiography, and LVEDV and LVESV were measured by dual-source electrocardiographically gated computed tomography.
[c] Percentage point change.
[d] Results were calculated on the basis of data from 83 patients.

may improve compliance with guidelines recommending early surgical repair. Pioneering series have demonstrated the feasibility of this approach and have paved the way for greater standardization and reproducibility of robotic MV repair.[8] The current report further demonstrates that robot-assisted MV repair can be performed expeditiously with zero mortality and a high success rate for all categories of leaflet prolapse by rigorously adhering to conventional open-repair indications, techniques, and follow-up. After successful robot-assisted MV repair, left ventricular (LV) size and volume regression occur almost immediately and continue 1 month after surgery.

It is well established that delaying MV repair in patients with severe MR is harmful. Allowing the LVEF to decrease below 60%, permitting expansion of left ventricular end-systolic diameter beyond 40 mm, or awaiting the onset of symptoms only increases early and late mortality after surgical correction.[7,9] In contrast, asymptomatic patients who undergo MV repair benefit with normalization of late survival,[10] improved regression of LV dimensions, and recovery of normal LVEF with time.[11] Those who advocate for watchful waiting point to the low rate of complications observed in a small cohort of young patients with normal LV systolic dimensions managed "medically."[12] The important question that arises when considering such an approach is this: Why should patients be denied therapy when the deleterious consequences of late intervention are inevitable and effective early surgical repair is available?

During the past 2 decades, outcome data from large academic centers have firmly established the superiority of MV repair over valve replacement for mitral leaflet prolapse.[10,13-15] Important factors explaining the recent improvement in the outcomes of MV repair include earlier surgical intervention[7,16] and, especially, standardization of repair techniques that are safe, expedient, and durable.[3] Triangular resection of a prolapsing posterior leaflet scallop is effective in eliminating prolapse and restoring normal leaflet coaptation. Anterior leaflet prolapse (and some posterior leaflet disease) is reproducibly repaired with artificial neochord resuspension.[4,17] At Mayo Clinic, all MV repairs are supported with an annuloplasty device. Although debate persists regarding the size, shape, and flexibility of such devices, recent evidence indicates that mitral annular dilation occurs largely in the posterior two-thirds of the mitral annulus in degenerative disease[5] and that annular reduction or stabilization using a flexible 63-mm posterior annuloplasty band is safe, effective, and durable.[18]

The transition from a proven transsternal platform for MV repair has been hindered by the inability to translate some less frequently used complex technical maneuvers into the nonsternotomy milieu. In contrast, the simplified open-repair techniques described in the current article are easily reproduced in their entirety in closed-chest robot-assisted operations. The additional learning curve required during robot-assisted MV repair has been well documented elsewhere[19] as well as in the current report. Cannulation for cardiopulmonary bypass is safe when performed in patients with normal vascular anatomy, which is best assessed using preoperative CT angiography. Myocardial protection during cardioplegic arrest is performed exactly as in an open transsternal operation with direct cannulation of the aortic root, which permits cardioplegia instillation and venting of left ventricle gaseous emboli. In the current series, there were no significant complications related to groin cannulation or transthoracic cross-clamp placement.

Reconstruction of mitral leaflet tissue after MV repair is performed with fine monofilament suture. The ability to tie these sutures using robotic assistance is limited by the tendency for these materials to fracture with direct compression. Therefore, the procedure described in the current report adhered to a policy of direct knot tying by the assisting surgeon using a knot pusher through ports to allow intracorporeal transthoracic delivery. This approach is reproducible and safe and allows use of the same stitches and annuloplasty devices that have contributed to long-term outcomes in published open-repair series.[10]

The complications encountered using a robot-assisted port access platform have generally been unrelated to the minimally invasive approach. The second patient in the current series, who had extensive Barlow disease of both the mitral leaflets and the mitral annulus, had annuloplasty band dehiscence more than 1 month after surgery and also had a stroke. At the time of reoperation, the tissues were of sufficiently poor quality that reanchoring a new annuloplasty device was not possible, which led to mechanical MV replacement. A patient with heparin-induced thrombocytopenia and thrombosis underwent bilateral fasciotomies secondary to microvascular thrombosis unrelated to cannulation site. Two patients underwent placement of coronary stents early in the postoperative period due to circumflex artery territory ischemia associated with coronary tethering, as has been described elsewhere after open MV repair.[20] Even with the utmost vigilance, especially during placement of stitches along the lateral portion of the mitral annulus in left dominant coronary circulations, the risk of angulation or "kinking" of the circumflex coronary artery due to tethering of adjacent tissue during reduction annuloplasty, with resulting limitations to coronary blood flow, is difficult to completely eliminate in either open or minimally invasive operations. Both patients had a guidewire passed easily, followed by delivery of an intracoronary stent, which promptly restored normal distal blood flow and ventricular function. One patient had an acute right coronary artery occlusion with distal thrombus. Intravascular ultrasonography was highly suggestive of mid-right coronary artery plaque with possible rupture and distal thrombus elaboration. This patient also had successful percutaneous restoration of distal blood flow and required temporary mechanical support, which facilitated recovery of normal biventricular function. One patient had documented paresis of the right hemidiaphragm, likely related to stay suture traction adjacent to the intact right phrenic nerve. In the procedure described herein, the pericardium is intentionally opened 4 cm anterior to the phrenic nerve to minimize the chance of such complications.

Prior series have demonstrated distinct benefits of minimally invasive MV repair, including decreased postoperative pain, shorter postoperative ventilation time, less frequent blood transfusion, improved respiratory function, equivalent or diminished postoperative length of hospitalization, and excellent safety and durability.[21-24] Robotic assistance can improve these outcomes by offering high-definition mobile videoscopic imaging and dynamic atrial retractor support along with wristed suturing capability through smaller endoscopic ports. Why, then, has robot-assisted valve repair been associated with wide variation in outcomes? We believe that reproducible results with use of the robotic platform have remained restricted to several highly specialized centers to date because proven open-repair techniques have been modified for application via endoscopic ports. The use of nitinol clips rather than hand-tied knots has diminished cross-clamp times in some series[25] but has also been associated with tissue tearing and annuloplasty dehiscence in others.[19] Cardioplegic arrest of the heart ensures a still, bloodless field during complex MV repair, and while endoaortic balloon occlusion may diminish the need for direct ascending aorta manipulation, it has been associated with increased cross-clamp or bypass times and a higher incidence of aortic dissection and stroke.[8,26] The procedure described herein adheres to myocardial preservation and left ventricle venting strategies that emulate an open approach. Transthoracic aortic root cannulation is performed with a long transthoracic tack vent secured by a purse-string suture placed robotically and direct transthoracic aortic occlusion using a long curved clamp. The reproducibility and safety of both cardioplegic arrest and postprocedural deairing have been satisfactory with use of this strategy. As experience increases, future modification of these techniques may allow their use not only for primary surgery but also for reoperations after lysis of adhesions. Proponents of a traditional sternotomy approach to the MV correctly cite impressive early outcomes, including an operative mortality of 1.41%, stroke rate of 1.11%, and median aortic cross-clamp time of 109 minutes for isolated MV repair, according to the Society of Thoracic Surgeons database.[27] As has been detailed in this report, all categories of mitral leaflet prolapse are equally repaired using these same conventional open techniques via small right-sided chest port incisions and robotic assistance. Importantly, this level of technical reproducibility is possible with zero mortality, a 1% risk of stroke, and a median aortic cross-clamp time of 81 minutes overall, which decreased to 57 minutes in the final 25 patients of the current series and continues its downward trend to date (last 25 cases, 49 minutes). The last point speaks to an important trend worldwide among teams adopting the robot-assisted platform; a considerable early learning curve exists, and improved outcomes can be expected with optimization of standard techniques and the accrual of team experience.[19,28,29] During this learning process, it is reassuring to patients, surgeons, and cardiologists alike that exactly the same operation is performed through a smaller incision with equivalent, if not better, early outcomes. It is precisely because standard open-repair techniques are upheld using robotic assistance that the late outcomes of this approach are expected to equal the proven long-term durability of open MV repair.[10]

An important advantage of operating on patients with severe MR early in the disease process is the ability to preserve the capacity for reverse remodeling of LV size, which permits recovery of normal LV function.[11,30] We previously demonstrated that early changes in LV dimensions after surgical correction of severe MV regurgitation include a decrease in LVEDD, with preservation of left ventricular end-systolic diameter, leading to a relative decrease in total LV output and an apparent early decrease in LVEF.[11] In the current series, the same trends in early LV remodeling were observed after robot-assisted MV repair. Prior work has established the importance of reverse LV remodeling to the return of LV function after surgical repair of chronic MR.[11]

LIMITATIONS

As acknowledged by others, patients offered robot-assisted or other minimally invasive mitral operations are necessarily selected.[21] As our robotic program was initiated at Mayo Clinic, we sought to address whether robot-assisted MV repair for all categories of leaflet prolapse could be performed with the same early safety and efficacy as sternotomy using conventional open-repair techniques. To answer this question, we excluded (1) patients with peripheral vascular disease precluding safe cannulation of the femoral vessels, (2) those with severe coronary artery disease who would otherwise undergo surgical coronary revascularization, and (3) those with prior sternotomy or right thoracotomy. A propensity analysis is under way to further clarify whether unsuspected heterogeneity beyond these characteristics exists between patients undergoing open and robotic procedures. The likelihood of MV repair for leaflet prolapse using either an open or robot-assisted MV repair is currently greater than 99% overall. Those who do not undergo repair in the current era are thought to have tissue characteristics that would preclude a successful outcome, such as severe leaflet or annular calcification, extensive tissue destruction (ie, severe endocarditis), or poor tissue quality incapable of allowing secure stitch placement. Finally, as follow-up accrues, summaries of intermediate and long-term outcomes are essential and will be forthcoming.

CONCLUSION

Robot-assisted MV repair to treat severe MR can be successfully performed for all categories of leaflet prolapse, with zero mortality, a median hospital stay of 3 days, and complication rates that are as low as, and in some cases lower than, those reported with traditional median sternotomy. Reliance on the use of standard open-repair techniques performed through minimally invasive port-access incisions is important. One month after surgery, those who undergo successful MV repair benefit from significant reverse remodeling of both LV size and volume. Future refinements of robotic valve surgery may improve patient safety further and expand the number of patients eligible for this approach, including those in need of reoperation.

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